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PROFILE-DRAG INVESTIGATION OF AN AIRPLANE WING EQUIPPED WITH RUBBER INFLATABLE DE-ICER

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SUMMARY

The National Advisory Committee for Aeronautics has made profile-drag measurements in flight of a wing which was equipped with a rubber inflatable de-icer and to which various simulated ice formations were attached. Tuft observations at the stalling speed of the wing with the various drag conditions were made in order to determine the influence on the maximum lift coefficient.

The de-icer installation caused an increase of from 10 to 20 percent in the profile drag of the plain wing and reduced $C_{L_{max}}$ about 6 percent. Simulated ice, when confined to the leading-edge region of the de-icer, had no measurable influence upon the profile drag at the cruising speed. This ice condition, however, reduced the value of $C_{L_{max}}$ to about three-fourths that of the plain wing.

Simulated ice in the form of a ridge along the upper and lower de-icer cap-strips increased the profile drag by about 360 percent at cruising speed. This condition reduced the $C_{L_{max}}$ to approximately one-half that of the plain wing value.

INTRODUCTION

The large number of airplanes equipped with rubber inflatable de-icers makes this device of considerable importance in aircraft operation and performance. Inquiries have frequently been made relative to the aerodynamic effect of the de-icer installation during flight in normal fair weather, and during icing conditions. A partial answer to these questions has been provided by previous investigations as reported in references 1, 2, and 3. In order to obtain more complete information, the National

Advisory Committee for Aeronautics has made flight measurements of the profile drag of an all-metal wing as influenced, first, by a rubber inflatable de-icer installation and, second, by simulated ice formations on the wing leading-edge region. Observations were also made on the approximate effect that the ice simulations had upon the maximum lift coefficient.

The pitot traverse method of measuring profile drag presented a relatively simple and accurate means of obtaining the required drag information (reference 4). Information regarding the lift coefficient was obtained by making tuft observations at the stalling speed of the test section.

APPARATUS AND METHOD

The flight tests were conducted on a Lockheed 12-A airplane which was equipped with inflatable wing de-icers (fig. 1). The details of the de-icer installation are shown in figure 2. The Lockheed wing is an all-metal structure with brazier-head rivets and lap-jointed skin. The traverse apparatus was located on the airplane in the position shown in figures 3 and 4. The necessary mechanism was provided for the movement of the traverse head through the arc AB (fig. 3) in measured increments during flight. To obtain a profile-drag measurement, a survey was made of the stream pressures between the two points A and B which were, respectively, above and below the wing wake. A swiveling air-speed head, shown in figure 1, was placed at the end of a boom projecting from the front of the fuselage, the calibration of which was established by means of a suspended pitot-static head. Pressure recordings of the following were made: (1) dynamic pressure of undisturbed stream; (2) dynamic pressure in the wake at each position of the traverse head; and (3) difference between the static pressures at these two points.

Profile-drag measurements and stalling-speed observations were obtained with the test section in the following conditions: (1) with de-icer, no ice (fig. 5); (2) with de-icer and formations on the leading edge (fig. 6); (3) with de-icer and formations on the leading edge and the de-icer attachment cap-strips (fig. 7); (4) with de-icer and with formations on the cap-strips only (fig. 8);

(5) plain wing without the de-icer and with the de-icer attachment rivnuts unfaired; and (6) with the de-icer removed and the rivnuts faired (fig. 9). The unfaired rivnuts of condition (5) can also be seen in figure 9.

Condition (1) corresponds to the state of the wing in normal operation when no ice is present. The simulations for conditions (2), (3), and (4) were obtained by fastening wooden blocks to the wing. The leading-edge blocks were $3/8$ inch by $3/8$ inch by 2 inches. The cap-strip pieces were triangular in section with $1/2$ -inch base and height, and ran continuously along the span of the test section. The simulated ice formations extended 50 inches along the leading edge of the wing. (See fig. 3.)

Attention is invited to the fact that the de-icer apparatus on the Lockheed 12-A airplane was installed within the past year and, therefore, is similar in surface smoothness to other de-icers currently in use and installed prior to January 1939. It is understood that various modifications of the de-icer are now under consideration for use during the coming winter (1939-1940). These modifications vary in degree from rather minor changes of existing equipment to completely new equipment for installation on new airplanes and are intended to reduce or eliminate the discontinuity in the wing contour at the rear edge of the de-icer. It is also understood that an improvement in surfacing the de-icer is now possible. These modifications are intended to reduce the profile drag of the plain wing and to prevent residual ice accretions on the leading-edge and the cap-strip regions. Inasmuch as these modifications are still in the development stage, no data are available regarding their effectiveness in eliminating ice accretions.

The determination of the thickness, shape, and location of the simulated ice was based on unpublished reports of flight observations on a rubber de-icer in action and on replies to a questionnaire circulated to transport airline operators. According to these sources, two different types of failure to remove ice are common. Ice may remain in narrow ridges along the leading edge of the de-icer when in operation, or an accumulation of ice may gather on the upper and lower cap-strips, or both types of failure to remove ice may occur simultaneously. Pictures of such ice formations, which were taken by the N.A.C.A. during a recent flight investigation, are shown in figure

10. For condition (5), the de-icer was removed and the rivnuts (to which the cap-strips are attached) were not faired. This situation corresponds to the normal condition of the wing during the summer. The rivnuts were then faired (condition (6)) in order to approach as closely as possible the profile drag of the plain Lockheed wing.

Tests were made with each of the six drag conditions at speeds of 125 and 175 miles per hour. Additional tests at 140 and 150 miles per hour were made with drag condition (1). The corresponding Reynolds Number range was from 6,500,000 to 9,000,000.

An approximation of the stalling speed of the test section for the various drag conditions was obtained from tuft observations. Ribbon tufts were fastened to the upper wing surface at the points indicated in figure 3. The air speed was decreased slowly until the ribbons indicated that the region of the test section had stalled. The speed at this instant was noted and was used to calculate $C_{L_{max}}$ for each condition. These tests were all made with the flaps up and the landing gear retracted.

RESULTS AND DISCUSSION

The equation for the profile-drag coefficient as given in reference 4 may be written

$$C_{D_0} = 2 \int_W \left(1 - \sqrt{\frac{H_1 - p_0}{H_0 - p_0}} \right) \left(\sqrt{\frac{H_1 - p_1}{H_0 - p_0}} \right) d \left(\frac{y}{c} \right)$$

where

y is distance measured across wake.

c , wing chord.

H_0 , total pressure of undisturbed stream.

p_0 , static pressure of undisturbed stream.

H_1 and p_1 , corresponding values in the survey plane.

Since $H_0 - p_0$ equals the dynamic pressure in the undisturbed stream and $H_1 - p_1$ equals the dynamic pressure at the survey head, then $H_1 - p_0$ equals the difference in static pressures subtracted from the survey dynamic pressure. The three pressure readings taken in flight were sufficient, therefore, to evaluate the quantity

$$\left(1 - \sqrt{\frac{H_1 - p_0}{H_0 - p_0}}\right) \left(\sqrt{\frac{H_1 - p_1}{H_0 - p_0}}\right)$$

for each value of y across the wake.

This quantity was plotted against y and, by multiplying the area under the curve so established by $2/c$, the value of C_{D_0} was obtained. A typical curve of the

data is shown in figure 11. During the 125-mile-per-hour runs of conditions (3) and (4), the width of the wake was so great that it could not be traversed by the survey mechanism; therefore the values for C_{D_0} were not obtained.

The results of the profile-drag investigation are shown in table I. The repetition of the data which will be noted for some of the drag conditions indicates that check flight tests were made for these conditions. The airplane lift coefficient during each drag test was calculated on a basis of the airplane wing loading and air speed. The profile-drag coefficient of the wing (at $C_L = 0.23$) with the rivnuts faired was found to be $C_{D_0} = 0.0095$. This is assumed to be substantially the same as the profile-drag coefficient of the wing section without the rivnuts and is called the plain-wing profile drag. The profile drag of the test section at the various conditions is compared with the plain-wing profile drag in column A (table I) and with the profile drag of the wing with de-icer in column B.

Removing the de-icer had the effect of reducing the section profile drag about 5 percent, and fairing the rivnuts resulted in a further reduction of 5 percent. Placing simulated ice on the de-icer at the leading edge did not measurably increase the profile drag at cruising air speed, although as the speed was reduced this was

not the case. At 125 miles per hour, the formations on the leading edge had caused an increase of 12 percent in the profile drag over that of the wing with a clean de-icer. Attaching a simulated ridge of ice on the upper and lower cap-strips and retaining the formation on the leading edge caused the profile drag of the wing at 175 miles per hour to become over four times its normal value. Removing the ice simulations from the leading edge but allowing the ridges on the cap-strips to remain caused a further increase in the profile drag at 175 miles per hour.

The results of the tuft observations at the speed of stall are given in table II. The maximum lift coefficient was calculated on a basis of the wing loading and the indicated air speed at the instant of stalling of the test section. The values for $C_{L_{max}}$ at the various drag conditions are compared with $C_{L_{max}}$ for the plain wing in column A (table II) and with $C_{L_{max}}$ of the wing with de-icer in column B.

Obtaining the values for C_L by tuft observations is admitted to be subject to error because of the effect of several factors which could not be evaluated in the present investigation. However, the lift data are thought to be of sufficient accuracy to show the approximate effect of the de-icer and the ice simulations on the lift coefficient. The de-icer installation without ice simulations reduced the value of $C_{L_{max}}$ below that for the plain wing by about 6 percent. Ice on the cap-strips reduced the $C_{L_{max}}$ to one-half the value obtained with clean de-icers.

Although the data were not determined for the landing conditions, the assumption is made that the lift coefficient during landing is similarly affected. A tendency of the airplane to roll during take-off and landing with only the 50 inches of test span affected indicates that the calculated data for $C_{L_{max}}$ are satisfactory approximations.

The simulated ice formation on the cap-strips necessitated a landing speed between 110 and 115 miles per hour, whereas the normal landing speed is in the vicinity of 70 miles per hour.

The significance of the data in table II and the observations made during the tests as applied to the Lockheed 12-A airplane may be briefly stated as follows:

The increases in the profile drag caused by the de-icer or by ice formations which are confined to the leading-edge region on the de-icer result in a reduction of less than 1 percent in the cruising speed, assuming constant power. At the speed for best rate of climb, however, the increase in profile drag due to the ice on the leading edge will result in a material reduction in the rate of climb.

Although the clean de-icer causes only a slight reduction in $C_{L_{max}}$, the presence of ice on the leading edge reduces this factor to the extent that the minimum safe landing speed is increased by about 14 percent above that of the clean wing. The minimum safe landing speed is calculated on a basis of the stalling speed of the wing cellule outboard from the engine nacelle to the wing tips and on which the de-icers are installed. According to similar calculations, ice on the de-icer attachment cap-strips increases the minimum safe landing speed about 50 percent above that for the plain wings.

CONCLUSIONS

1. The installation of the rubber inflatable de-icers increased the profile drag of the plain Lockheed wing by 10 percent at $C_L = 0.23$ and by 20 percent at $C_L = 0.45$.

2. The attachment of simulated ice to the leading-edge region of the de-icer resulted in a wing profile drag (at $C_L = 0.23$) which was not measurably different from that obtained with the clean de-icer. At $C_L = 0.45$, however, this condition increased the profile drag 35 percent above that of the plain wing and 15 percent above that of the wing with clean de-icer.

3. A formation of simulated ice along the upper and lower de-icer cap-strips increased the profile drag of the plain wing by approximately 360 percent at $C_L = 0.23$.

4. On the basis of tuft observations at the stalling speed, ice on the leading edge of the airplane wing may reduce the value of $C_{L_{max}}$ 25 percent, while ice only on the de-icer cap-strips may reduce $C_{L_{max}}$ 59 percent below that of the plain Lockheed wing.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 14, 1939.

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1. Jacobs, Eastman H.: Airfoil Section Characteristics as Affected by Protuberances. T.R. No. 446, N.A.C.A., 1932.
2. Jacobs, Eastman N., and Sherman, Albert: Wing Characteristics as Affected by Protuberances of Short Span. T.R. No. 449, N.A.C.A., 1933.
3. Robinson, Russell G.: The Drag of Inflatable Rubber De-icers. T.N. No. 669, N.A.C.A., 1938.
4. Bicknell, Joseph: Determination of the Profile Drag of an Airplane Wing in Flight at High Reynolds Numbers. T.R. No. 667, N.A.C.A., 1939.

TABLE I.- DRAG OF WING AS INFLUENCED BY RUBBER INFLATABLE DE-ICER AND SIMULATED ICE FORMATIONS

Drag condition	Description of condition	Test section profile-drag coefficient, C_{D_0}	Airplane lift coefficient, C_L	Reynolds Number	A Profile drag in percent of profile drag of plain wing	B Profile drag in percent of profile drag of wing with de-icer
(1)	De-icer, no ice	0.0105	0.23	9.0×10^6	110	100
		.0105	.23	9.0	-	-
		.0113	.31	7.0	-	-
		.0116	.36	7.1	-	-
		.0124	.44	6.6	120	100
		.0126	.47	6.4	-	-
(2)	De-icer, and ice on leading-edge region	.0105	.23	9.2	110	100
		.0139	.44	6.6	135	112
(3)	De-icer, and ice on leading edge and cap-strips	.0435	.23	9.1	458	414
(4)	De-icer, and ice on cap-strips only	.0455	.23	9.2	480	433
(5)	De-icer removed, rivnuts unfaired	.0099	.23	9.0	104	94
		.0111	.45	6.6	107	89
(6)	De-icer removed, rivnuts faired	.0093	.22	9.5	-	-
		.0095	.23	9.3	100	91
		.0103	.45	6.6	100	83
		.0106	.45	6.7	-	-

20 0
7 10 6
0 6 8 10 12 14 18
N/V

TABLE II.- MAXIMUM LIFT DATA FOR TEST SECTION OF WING

Drag condition	Description of condition	Indicated stalling speed V_i (m.p.h.)	Approximate section maximum lift coefficient, $C_{l_{max}}$	$C_{L_{max}}$ in percent of $C_{L_{max}}$ for plain wing, A	$C_{L_{max}}$ in percent of $C_{L_{max}}$ for wing with de-icer B
(1)	De-icer, no ice	74.1	1.36	94	100
(2)	De-icer, and ice on leading-edge region	83.3	1.07	74	79
(3)	De-icer, and ice on leading edge and cap-strips	102.7	.71	49	52
(4)	De-icer, and ice on cap-strips only	112.8	.59	41	43
(5)	De-icer removed, rivnuts unfaired	72.0	1.44	100	106
(6)	De-icer removed, rivnuts faired	72.0	1.44	100	106

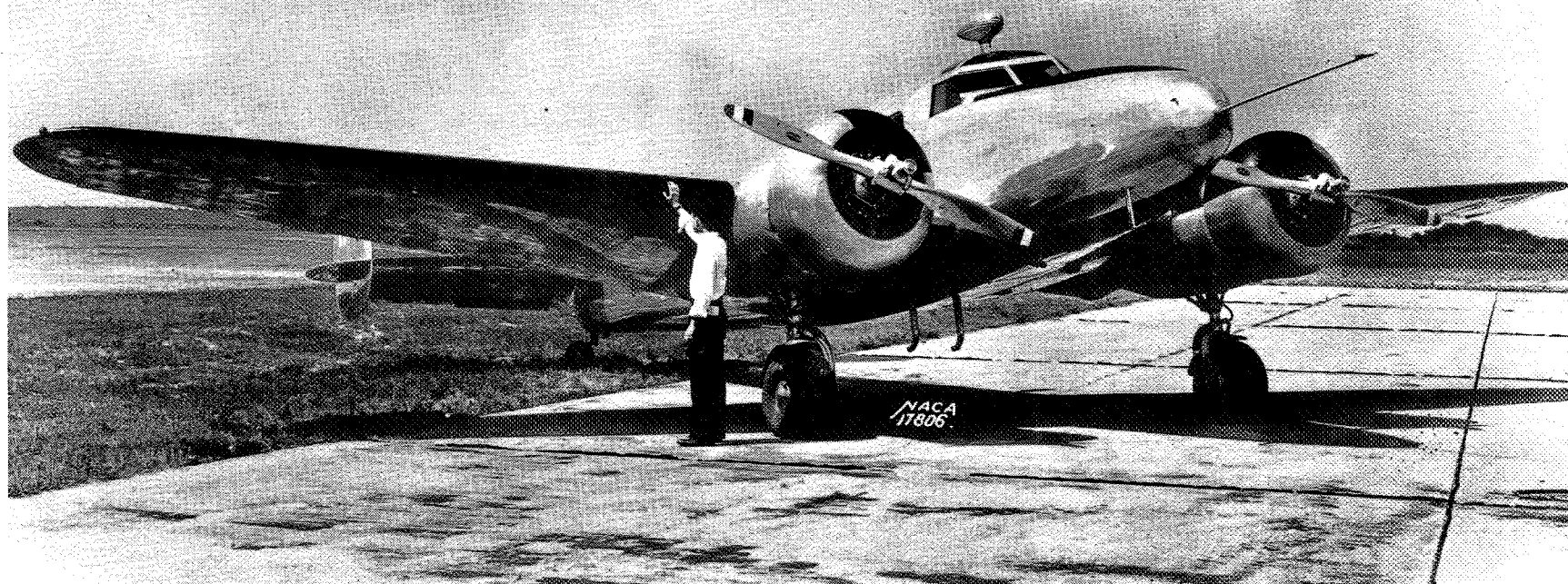
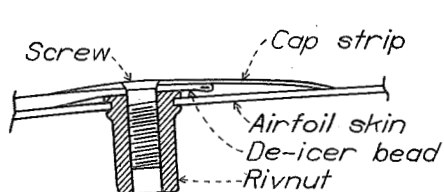
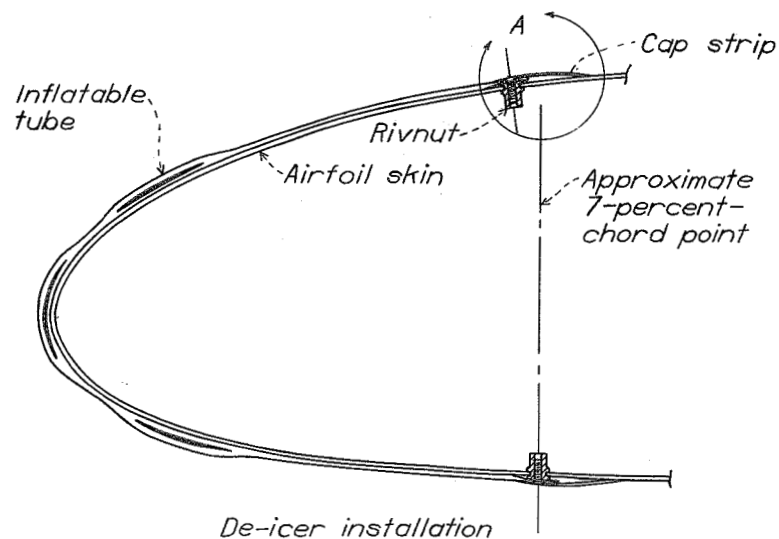
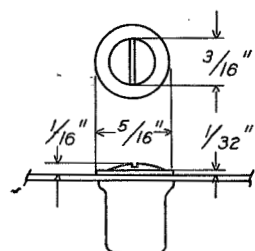


Figure 1.- Lockheed 12-A airplane equipped with inflatable de-icers.



View A
Cap-strip attachment details.



Dimensions for portion of rivnut in air stream during condition (5).

Figure 2. Rubber inflatable deicer details.

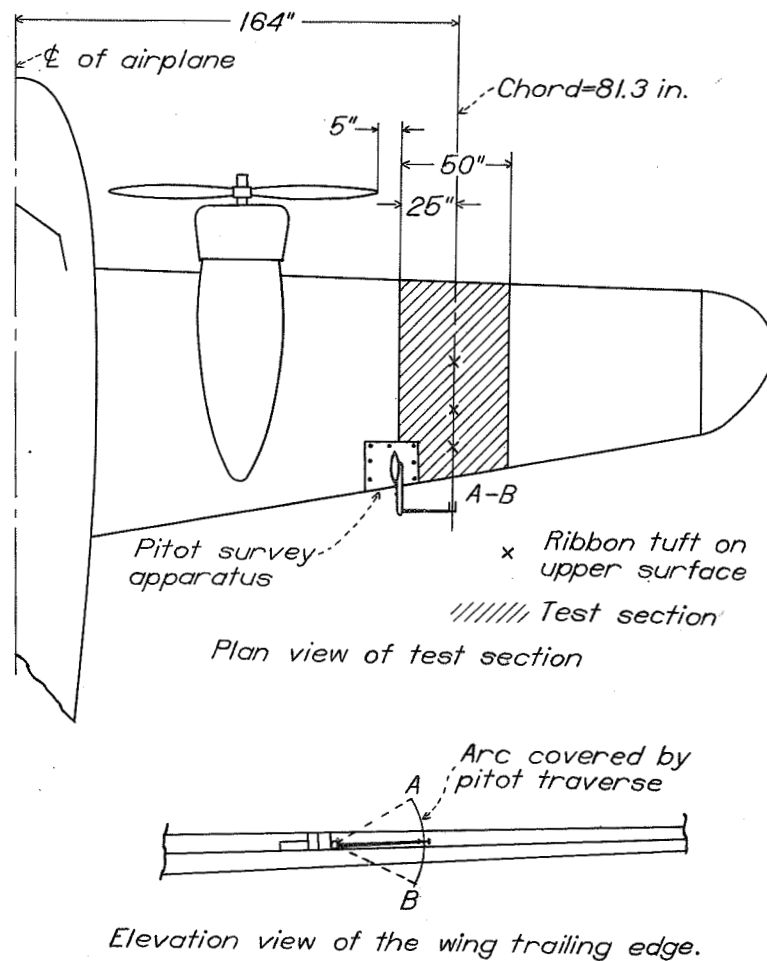


Figure 3. Location of test section and traverse apparatus.

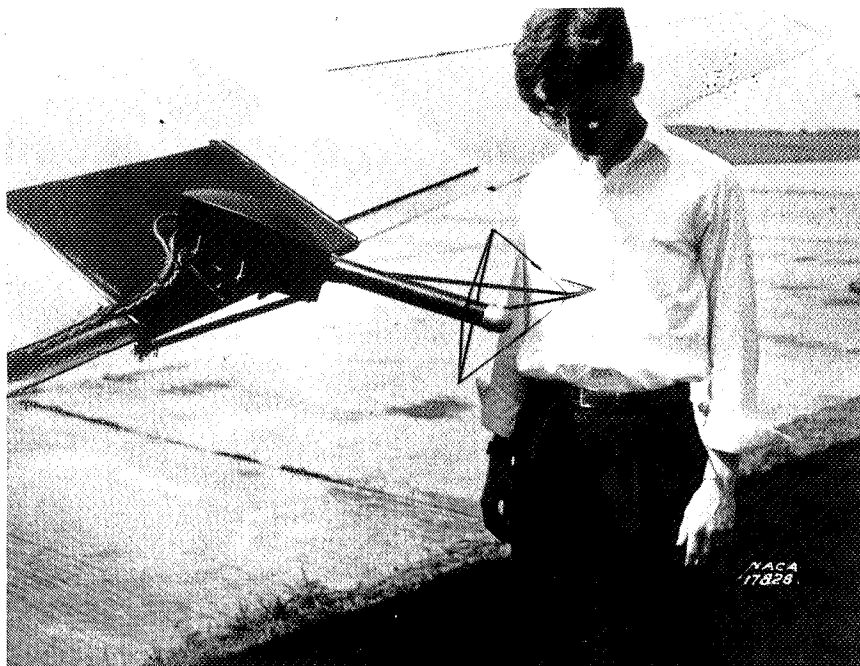


Figure 4.- Wake-survey apparatus installed on the trailing edge of the wing.



Figure 5.- Rubber inflatable de-icer installation. Drag condition (1).

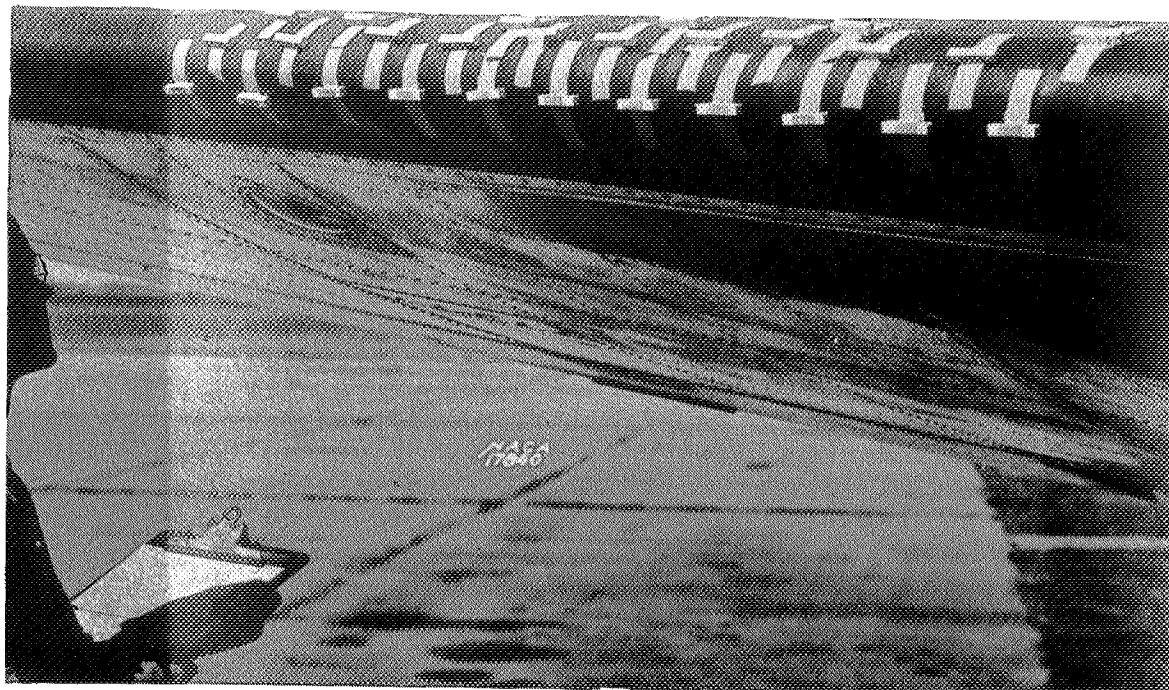


Figure 6.- Rubber de-icer with simulated ice formations on leading edge. Drag condition (2).

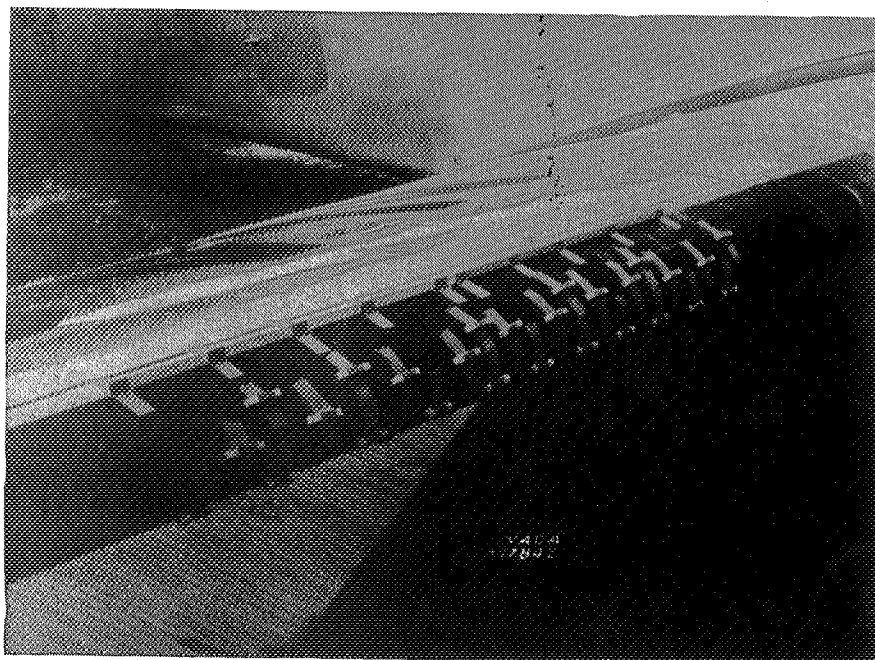


Figure 7.- Rubber de-icer with simulated ice formations on leading edge and with upper and lower cap strips. Drag condition (3).

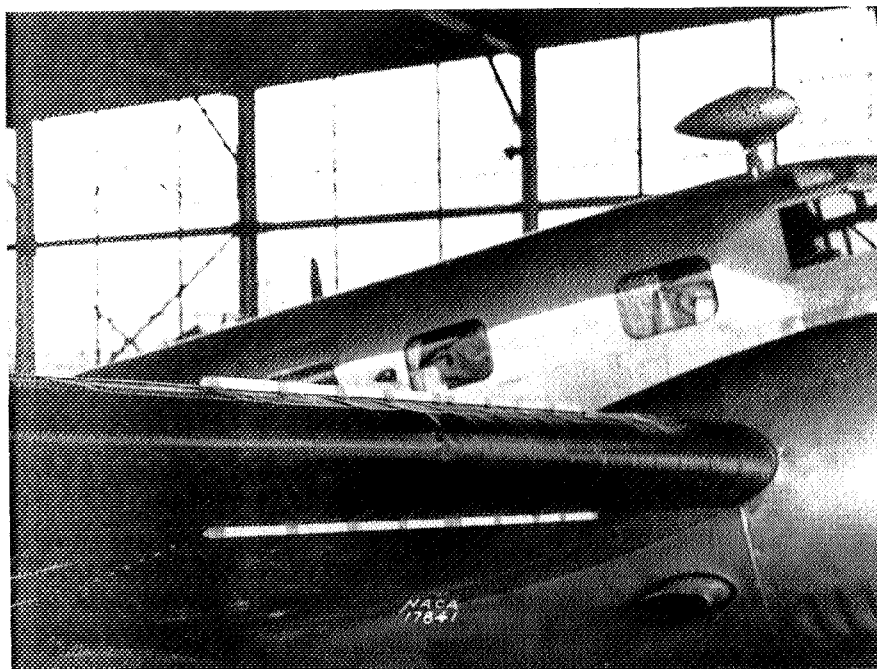


Figure 8.- Rubber de-icer with simulated ice only on cap strips. Drag condition (4).

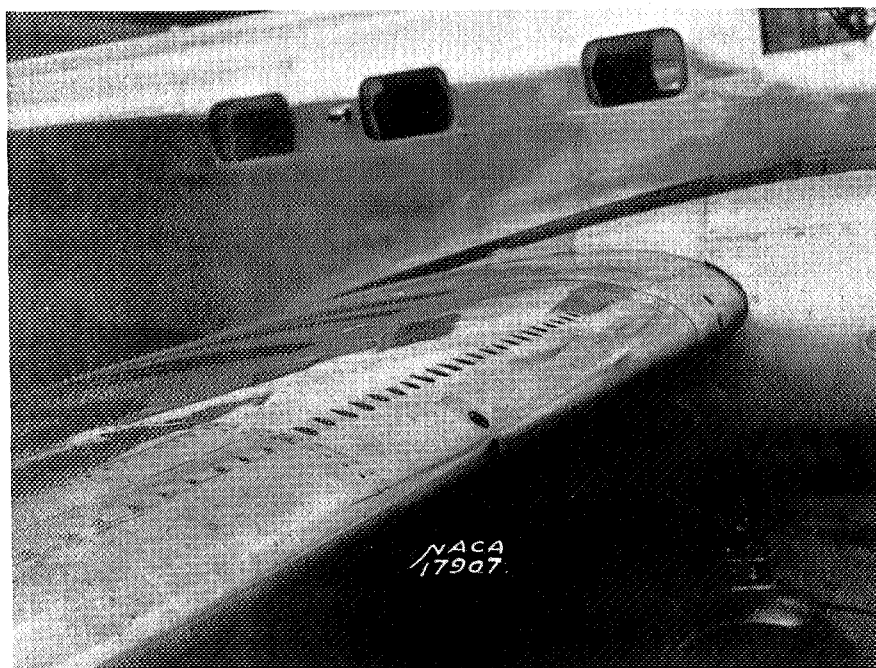
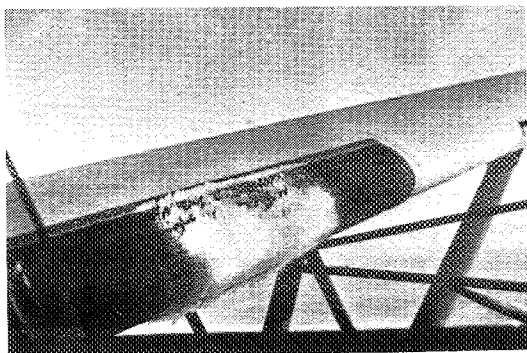
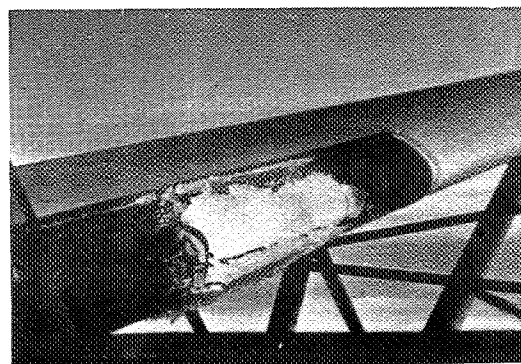


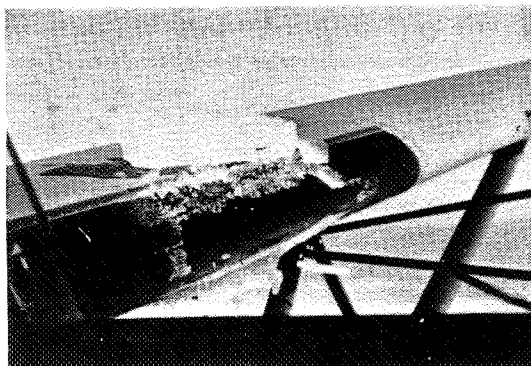
Figure 9.- Rubber de-icer removed and rivnuts faired. Drag condition (6). The unfaired rivnuts can be seen at the left of the test section.



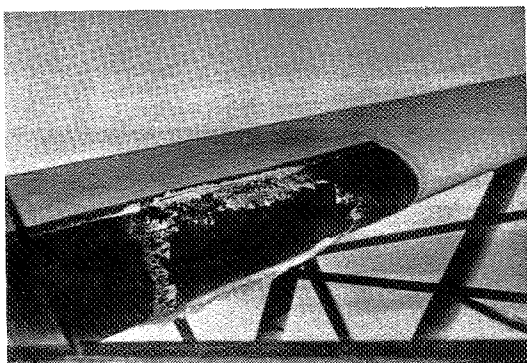
(a) Glaze ice formed at 27° F. before the de-icer was turned on.



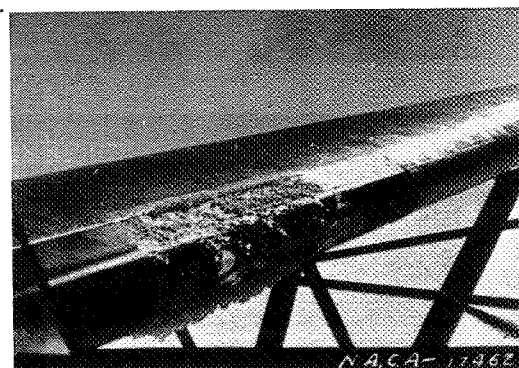
(b) The formation illustrated in (a) being broken up by the inflation of the de-icer.



(c) The continuation of the removal of the ice formation shown in (a).



(d) The de-icer after the removal of ice from the leading edge. Note the ice remaining on the upper and lower attachment cap strips.



(e) The de-icer in continuous operation under icing conditions at an air temperature of 27° F.

Figure 10.- The Goodrich de-icer in operation during a test at the N.A.C.A.

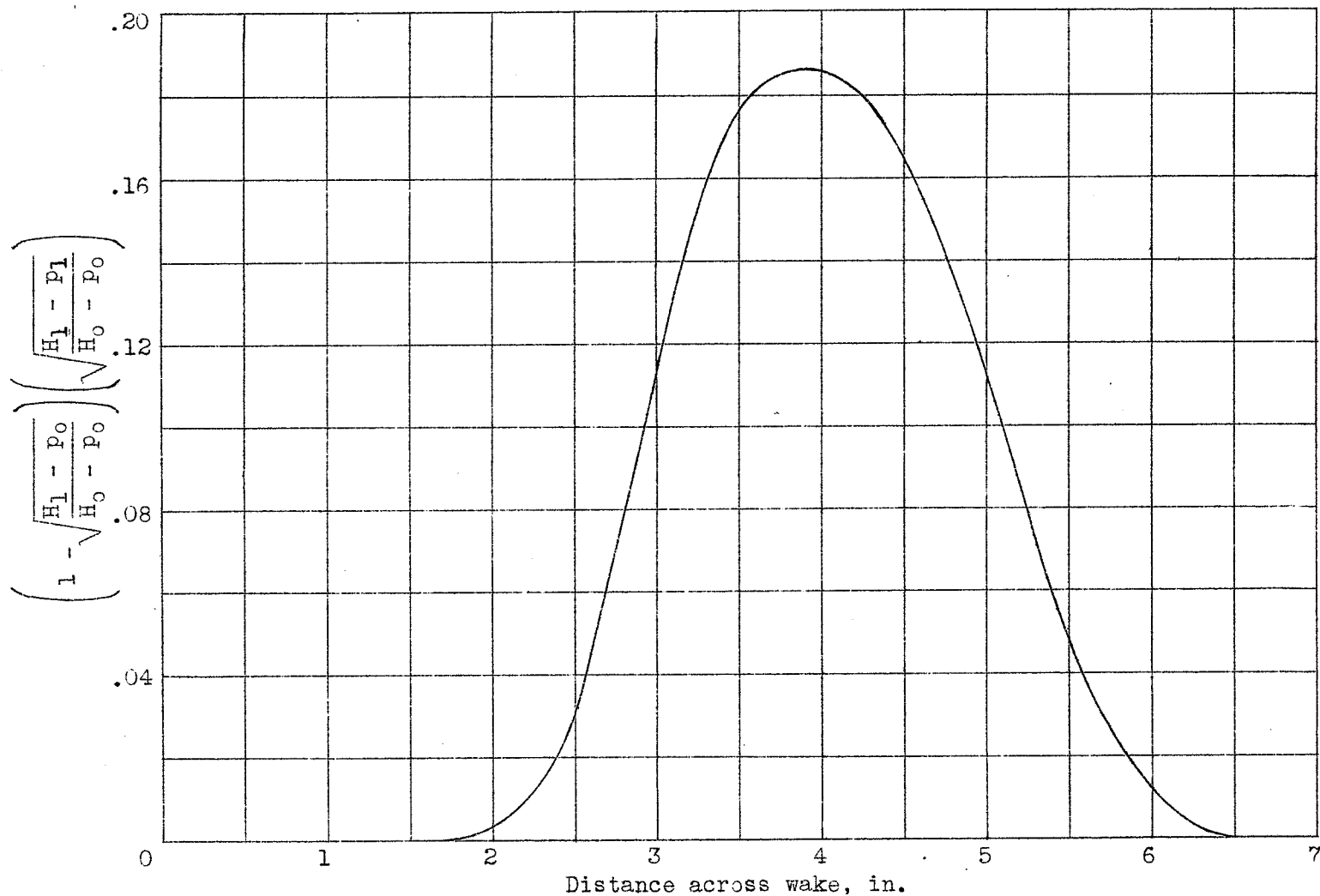


Figure 11.- Wake-survey curve for Lockheed 12-A wing with rubber de-icer and simulated ice on leading edge. Air speed, 175 miles per hour; chord at survey head, 81.3 inches.